UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS / Ernest Ambler, Director

Special Publication 304A Revised August 1981

Brief History of MEASUREMENT SYSTEMS

with a Chart of the Modernized Metric System

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."

JOHN QUINCY ADAMS
Report to the Congress, 1821

Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds which were then counted to measure the volumes. When means for weighing were invented, seeds and stones served as standards. For instance, the "carat," still used as a unit for gems, was derived from the carob seed.

As societies evolved, weights and measures became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of weights and measures suited to trade and commerce, land division, taxation, or scientific research. For these more sophisticated uses it was necessary not only to weigh and measure more complex things—it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world—even in different parts of a single continent.

The English System

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures—Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman French. The ancient "digit," "palm," "span," and "cubit" units evolved into the "inch," "foot," and "yard" through a complicated transformation not yet fully understood.

Roman contributions include the use of the number 12 as a base (our foot is divided into 12 inches) and words from which we derive many of our present weights and measures names. For example, the 12 divisions of the Roman "pes," or foot, were called *unciae*. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to the early Saxon kings. They wore a sash or girdle around the waist—that could be removed and used as a convenient measuring device. Thus the word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardization of the various units and their combinations into a loosely related system of weights and measures sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that the yard should be the distance from the tip of his nose to the end of his thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5 000 feet would be replaced by one of 5 280 feet, making the mile exactly 8 furlongs and providing a convenient relationship between two previously ill-related measures.

Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than the continental countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through colonization and dominance of world commerce during the 17th, 18th,

THE MODERNIZED metric system

The International System of Units-SI

is a modernized version of the metric system established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, plus two supplementary units, which appear on this chart along with their definitions. All other SI units are derived from these units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the customary and metric systems.

COMMON CONVERSIONS

Accurate to Six Significant Figures

Symbol	When You Know Number Of	Multiply by	To Find Number Of	Symbol
in	inches	[A] 25.4	[B] millimeters	mm
ft	feet	[A] 0.3048	meters	m
yd	yards	[A] 0.9144	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^2
	acres	0.404 686	[C] hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	[D] liters	L
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	0.453 592	kilograms	kg
°F	degrees Fahrenheit	[A] 5/9 (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^2
ha	[C] hectares	2.471 05	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
L	[D] liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	[A] 9/5 (then add 32)	degrees Fahrenheit	°F

[A] exact

[B] for example, 1 in = 25.4 mm, so 3 inches would be $(3\ \text{in})(25.4\ \frac{\text{mm}}{\text{in}}) = 76.2\ \text{mm}$

[C] hectare is a common name for 10 000 square meters

[D] liter is a common name for fluid volume of 0.001 cubic meter

[E] apply to gram in case of mass

Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

MULTIPLES AND PREFIXES

These Prefixes May Be Applied To All SI Units

Multiples and Submultiples		Prefixes	Symbols
1 000 000 000 000 000 000 =	10^{18}	exa (ĕx' a)	E
1 000 000 000 000 000 =	10^{15}	peta (pĕt' a)	P
1 000 000 000 000 =	10^{12}	tera (tĕr' a)	T
1 000 000 000 =	10^{9}	giga (jĭ' ga)	G
1 000 000 =	10^{6}	mega (mĕg' a)	M
1 000 =	10^{3}	kilo (kĭl' ō)	k
100 =	10^{2}	hecto (hĕk' tō)	h
10 =	10^{1}	deka (dĕk' a)	da
1 =	10^{0}		
0.1 =	10^{-1}	deci (dĕs' ĭ)	d
0.01 =	10^{-2}	centi (sĕn' tĭ)	c [E]
0.001 =	10^{-3}	milli (mĭl' ĭ)	m
0.000 001 =	10^{-6}	micro (mī' krō)	µ
0.000 000 001 =	10^{-9}	nano (năn' ō)	n
0.000 000 000 001 =	10^{-12}	pico (pē' kō)	p
0.000 000 000 000 001 =	10^{-15}	femto (fĕm' tō)	f
0.000 000 000 000 000 001 =	10^{-18}	atto (ăt' tō)	a

National Bureau of Standards
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REFERENCES

NBS Special Publication 330, latest edition, International System of Units (SI), available by purchase from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402

ASTM Standard for Metric Practice E380-79, available by purchase from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103

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meter-m
LENGTH

The meter is define
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of krypton 86

kilogram-kg
MASS

The sta
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TIME

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ampere-A
ELECTRIC CURRENT

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kelvin-K
TEMPERATURE

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point of water. The
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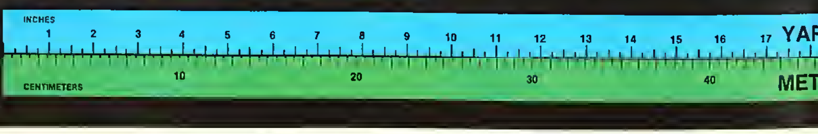
mole-mol
AMOUNT OF SUBSTANC

candela-cd
LUMINOUS INTENSITY

radian-rad
PLANE ANGLE

The radian is the p
vertex at the cente
subtended by an a
the radius.

Note: Not to Scale



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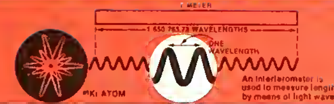
U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

SEVEN BASE UNITS

meter-m LENGTH

The meter is defined as 1 650 763.73 wavelengths in vacuum of the orange-red line of the spectrum of krypton-86.



The SI unit of area is the square meter (m^2).

The SI unit of volume is the cubic meter (m^3). The liter (0.001 cubic meter), although not an SI unit, is commonly used to measure fluid volume.

kilogram-kg MASS

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

The SI unit of force is the newton (N). One newton is the force which, when applied to a 1-kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.

$1\ N = 1\ kg{\cdot}m/s^2$

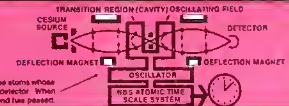
The SI unit for pressure is the pascal (Pa).
$Pa = 1\ N/m^2$

The SI unit for work and energy of any kind is the joule (J).
$1\ J = 1\ N{\cdot}m$

The SI unit for power of any kind is the watt (W).
$1\ W = 1\ J/s$

second-s TIME

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium-133 atom. It is realized by tuning an oscillator to the resonance frequency of cesium-133 atoms as they pass through a system of magnets and a resonant cavity into a detector.



Schematic diagram of an atomic beam spectrometer or "clock." Only those atoms whose magnetic moments are "flipped" in the transition region reach the detector. When 9 192 631 770 oscillations have occurred, the clock indicates one second has passed.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

The SI unit for speed is the meter per second (m/s).

The SI unit for acceleration is the (meter per second) per second (m/s^2).

Standard frequencies and correct time are broadcast from WWV, WWVB, and WWVH, and stations of the U.S. Navy. Many shortwave receivers pick up WWV and WWVH, on frequencies of 2.5, 5, 10, 15, and 20 megahertz.

ampere-A ELECTRIC CURRENT

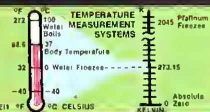
The ampere is defined as that current which, if maintained in each of two long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of 2×10^{-7} newton for each meter of length.

The SI unit of voltage is the volt (V).
$1\ V = 1\ W/A$

The SI unit of electric resistance is the ohm (Ω).
$1\ \Omega = 1\ V/A$

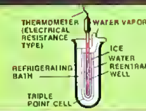
kelvin-K TEMPERATURE

The kelvin is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is called "absolute zero."



On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

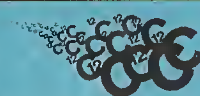
1.8 Fahrenheit degrees are equal to 1.0 °C or 1.0 K; the Fahrenheit scale uses 32 °F as a temperature corresponding to 0 °C.



The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.

mole-mol AMOUNT OF SUBSTANCE

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.



When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the mole per cubic meter (mol/m^3).

candela-cd LUMINOUS INTENSITY

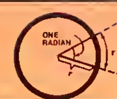
The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.

Radiation at frequencies other than 540×10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, V(λ), curve that peaks at 540×10^{12} Hz (yellow green).

TWO SUPPLEMENTARY UNITS

radian-rad PLANE ANGLE

The radian is the plane angle with its vertex at the center of a circle that is subtended by an arc equal in length to the radius.



steradian-sr SOLID ANGLE

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.

Note: Not to Scale

INCHES 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 YARD 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

CENTIMETERS 10 20 30 40 METER 50 60 70 80 90

A full scale wall chart, NBS Special Publication 304 is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

and 19th centuries, the English system of weights and measures was spread to and established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce among the 13 colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) giving power to the Congress to fix uniform standards for weights and measures. Today, standards supplied to all the States by the National Bureau of Standards assure uniformity throughout the country.

The Metric System

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul in Lyons, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the earth. In 1671 Jean Picard, a French astronomer, proposed the length of a pendulum beating seconds as the unit of length. (Such a pendulum would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards.) Other proposals were made, but over a century elapsed before any action was taken.

In 1790, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the earth's circumference. Measures for capacity (volume) and mass (weight) were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, the larger and smaller versions of each unit were to be created by multiplying or dividing the basic units by 10 and its powers. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus the metric system is a "base-10" or "decimal" system.

The Commission assigned the name *metre* — which we spell meter — to the unit of length. This name was derived from the Greek word *metron*, meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the north pole to the equator along the meridian of the earth running near Dunkirk in France and Barcelona in Spain.

The metric unit of mass, called the "gram," was defined as the mass of one cubic centimeter (a cube that is 1/100 of a meter on each side) of water at its temperature of maximum density. The cubic decimeter (a cube 1/10 of a meter on each side) was chosen as the unit of fluid capacity. This measure was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized character and decimal features of the metric system made it well suited to scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it was made "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."

By the late 1860's, even better metric standards were needed to keep pace with scientific advances. In 1875, an international treaty, the "Treaty of the Meter," set up well-defined metric standards for length and mass, and established permanent machinery to recommend and adopt further refinements in the metric system. This treaty, known as the Metric Convention, was signed by 17 countries, including the United States.

As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally agreed-to metric standards have served as the fundamental weights and measures standards of the United States.

By 1900 a total of 35 nations—including the major nations of continental Europe and most of South America—had officially accepted the metric system. In 1971 the Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated national program. The Congress responded by enacting the Metric Conversion Act of 1975. Today, with the exception of a few small countries, the entire world is using the metric system or is changing to such use.

The International Bureau of Weights and Measures located at Sevres, France, serves as a permanent secretariat for the Meter Convention, coordinating the exchange of information about the use and refinement of the metric system. As measurement science develops more precise and easily reproducible ways of defining the measurement units, the General Conference on Weights and Measures—the diplomatic organization made up of adherents to the Convention—meets periodically to ratify improvements in the system and the standards.

In 1960, the General Conference adopted an extensive revision and simplification of the system. The name *Le Système International d'Unités* (International System of Units), with the international abbreviation SI, was adopted for this modernized metric system. Further improvements in and additions to SI were made by the General Conference in 1964, 1968, 1971, 1975, and 1979.

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